Executive Summary

Flexographic Ink Options: A Cleaner Technologies Substitutes Assessment (the Flexographic Inks CTSA) presents the results of a technical study of the comparative environmental impacts, health risks, performance, and cost of the three primary flexographic printing ink systems: solvent-based inks, water-based inks, and ultra-violet (UV)-cured inks. The study was initiated through the Flexography Partnership of the Design for the Environment (DfE) Program at the U.S. Environmental Protection Agency (EPA).* The broad goal of the CTSA was to develop as complete and systematic a picture as possible of competing ink technologies, thereby helping industry incorporate environmental and health information into their ink decisions. It is hoped that the CTSA will serve as a resource to

- identify and inform industry about comparative chemical risks in inks, including unregulated ones that present opportunities for proactive, voluntary risk management,
- facilitate the use and formulation of cleaner inks, and
- encourage adoption of workplace practices that minimize health and environmental risks from exposure to chemicals of concern.

The study examined ink systems that are used on wide-web film substrates, a combination that presented special technical and environmental challenges for printers. Notably, at the time the study was initiated, use of UV-cured inks on wide-web film substrates was still in a developmental stage and was just beginning to emerge commercially. One of the benefits of the CTSA approach is its ability to provide unbiased insights into the environmental and health impacts and competitiveness of emerging technologies.

Interestingly, the CTSA found that each of the ink systems studied had different advantages, as well as health and environmental concerns. Considerable variation was noted even among different colors within a single ink product line. Thus, *selecting the best formulations is just as important for a printer as selecting an ink system.* The CTSA results can help printers and formulators familiarize themselves with the toxicities of chemicals they use on a daily basis, be more aware of their risk concerns, and identify cleaner ink systems, formulations, and chemicals.

The primary audiences for the Flexographic Inks CTSA are flexographic printers, ink manufacturers, environmental health and safety personnel, community groups, and other technically informed decision makers.

* EPA's Design for the Environment Program is located within the Economics, Exposure and Technology Division, in the Office of Pollution Prevention and Toxics.

The Flexography Partnership is a voluntary, cooperative effort among EPA, industry, academia, public interest groups, and other stakeholders. Project partners participated in all stages of planning and implementing this CTSA. They helped define its scope and direction, provided technical information, reviewed data and text, and donated time, materials, and printing facilities for performance demonstrations. Critical information about ink formulations used in the analyses was provided by ink manufacturers.

In addition to the Flexographic Inks CTSA, the Flexography Partnership has developed a summary report, a pollution prevention video, and a number of other materials for printers. These may be obtained from the DfE website (www.epa.gov/dfe) or by contacting EPA's National Service Center for Environmental Publications (telephone 800-490-9198 or 513-489-8190; fax 513-489-8695; Internet address www.epa.gov/ncepihom/ordering.htm; e-mail ncepimal@one.net).

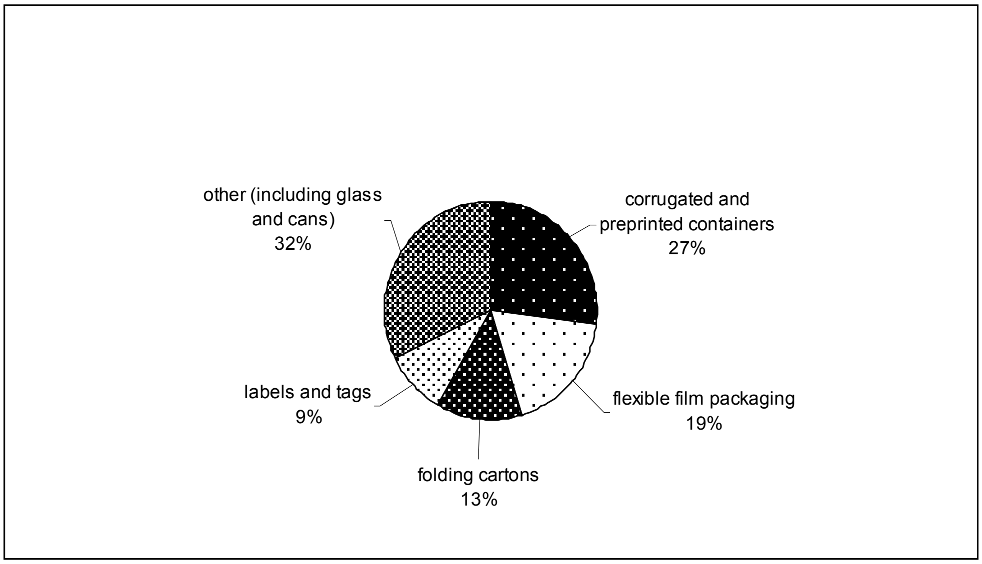
This Executive Summary first provides a brief background of the flexographic industry, the DfE Program, and the Flexographic Inks CTSA. It then presents key results on the main research areas: environmental impacts and health concerns, performance, and costs. It ends with some steps that flexographic professionals could take to minimize impacts on the environment and worker health.

BACKGROUND OF THE DFE FLEXOGRAPHY PROJECT

The Flexographic Printing Industry

Flexography is a process used primarily for printing on paper, corrugated paperboard, and flexible plastic materials. Especially well suited to printing on flexible and non-uniform surfaces (such as plastic films and corrugated board), flexography is used to print a wide range of products we all use, such as snack food and frozen food bags, labels for medicines and personal care products, newspapers, drink bottles, and cereal containers (Figure ES.1).

Figure ES.1 Primary Types of Packaging Manufactured in the United States, 2000
(by % of sales dollars)



Flexography is a highly visible, growing, national industry that is dominated by small businesses. Combined, these businesses have the potential to make a major environmental impact, especially on air quality, resource use (e.g., inks and substrates), and solid and hazardous waste.

- U.S. flexographic printing firms had annual sales of approximately $50 billion in 1999.[1]
- The sector employs about 30,000 people.[2]
- More than 80% of all flexography firms have fewer than 50 employees.
- It has an annual growth rate of about 6%.[3]
- Roughly 60% of flexographic businesses are concentrated in ten states: California, Florida, Illinois, Missouri, New Jersey, New York, North Carolina, Ohio, Texas, and Wisconsin.[4]
- Flexographic printing consumed more than 513 million pounds of ink in 2000.[5]

EPA's Design for the Environment Program

The Design for the Environment (DfE) Program is a voluntary partnership program that works directly with industries, usually through industry leaders and trade or technical associations, to integrate health and environmental considerations into their business decisions. The DfE approach compares the human health and environmental risks, performance, and costs associated with existing and alternative technologies or processes. DfE helps businesses design or redesign products, processes, and management systems that are cleaner, more cost-effective, and safer for workers and the public.

DfE partnerships may take several approaches to designing for the environment: technology assessments, formulator approaches, best practices approaches, greening the supply chain, integrated environmental management systems, and life-cycle assessments. DfE has established partnerships in commercial printing (flexography, lithography, and screen printing), garment and textile care, computer monitors, printing wiring boards (used for computers and other electronics), industrial and institutional cleaning formulations, automotive refinishing, adhesives used in foam furniture and sleep products, and automotive suppliers.

Background and General Methodology of the Flexographic Inks CTSA

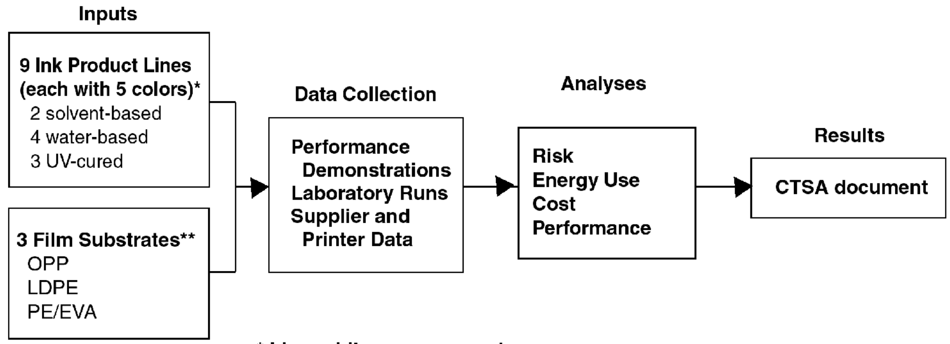
In the mid-1990s, DfE identified flexography as an important industry sector that could benefit from a DfE assessment:

- Historically, most flexographic inks had been solvent-based, had high levels of volatile organic compounds (VOCs), and contained many chemicals, some of which were quite toxic. Although the printing industry has addressed a number of environmental and health concerns of inks through reformulation of inks, add-on pollution control devices, and other improvements to operations and materials, these had not resolved all concerns about human health and ecological risks.
- Inks are a major use and cost category for printers.
- As small businesses, individual flexography firms might not have the resources or expertise to research the environmental implications of competing technologies.
- The industry had been growing rapidly for several years, which increases its impacts.

The Flexography Partnership decided to perform a cleaner technologies substitutes assessment or CTSA for flexographic inks. This methodology allowed the Partners to evaluate traditional and alternative technologies for the potential risks they pose to human health and the environment, as well as for performance and cost. The CTSA methodology is described in the DfE document, *Cleaner Technologies Substitutes Assessment: A Methodology and Resources Guide*.[**] Figure ES.2 graphically displays the methodology used for this CTSA.

[**] See the beginning of this volume (page ii) for ordering information.

Figure ES.2 Flexographic Inks CTSA Methodology



* blue, white, cyan, magenta, green.
** OPP = oriented polypropylene. LDPE = low-density polyethylene.
PE/EVA = polyethylene/ethyl vinyl acetate co-extruded film.

ENVIRONMENTAL IMPACTS AND HEALTH CONCERNS

This section describes the risk assessment methodology that was used to obtain and evaluate the health and environmental findings for flexographic inks. Findings related to workers and the general population are discussed first. Environmental findings follow, including (1) ambient air releases, (2) aquatic toxicity, and (3) resource use and energy conservation.

Over the past decade, ink manufacturers have made environmental improvements by developing inks with lower VOC content. The Flexography Partnership wanted to obtain an even deeper understanding of environmental and health implications of ink chemicals, to help the industry innovate and select cleaner inks, and to ensure that new formulations were not shifting risks from one medium to another (e.g., from ambient air quality to worker health).

The study examined 45 ink formulations, which contained approximately 100 chemical substances (Table ES.1). Ink suppliers voluntarily provided the inks, along with complete information about the chemical compositions of their formulations. To compare the environmental and health implications of the three ink systems, the study examined the toxicity, estimated releases and exposures, and risk concerns for the chemicals. To protect manufacturers' confidentiality, the formulation information they provided was treated as confidential business information.

Table ES.1 Categorization of Ink Chemicals

Category	Chemicals in category	CAS number
Acrylated polyols	Dipropylene glycol diacrylate 1,6-Hexanediol diacrylate Hydroxypropyl acrylate Trimethylolpropane triacrylate	57472-68-1 13048-33-4 25584-83-2 15625-89-5
Acrylated polymers	Acrylated epoxy polymer[c] Acrylated oligoamine polymer[c] Acrylated polyester polymer (#'s 1 and 2)[c] Glycerol propoxylate triacrylate Trimethylolpropane ethoxylate triacrylate Trimethylolpropane propoxylate triacrylate	NA[a] NA NA 52408-84-1 28961-43-5 53879-54-2
Acrylic acid polymers	Acrylic acid-butyl acrylate-methyl methacrylate-styrene polymer Acrylic acid polymer, acidic (#'s 1 and 2)[c] Acrylic acid polymer, insoluble[c] Butyl acrylate-methacrylic acid-methyl methacrylate polymer Styrene acrylic acid polymer (#'s 1 and 2)[c] Styrene acrylic acid resin[c]	27306-39-4 NA NA 25035-69-2 NA NA
Alcohols	Ethanol Isobutanol Isopropanol Propanol Tetramethyldecyndiol	64-17-5 78-83-1 67-63-0 71-23-8 126-86-3
Alkyl acetates	Butyl acetate Ethyl acetate Propyl acetate	123-86-4 141-78-6 109-60-4
Amides or nitrogenous compounds	Amides, tallow, hydrogenated Ammonia Ammonium hydroxide Erucamide Ethanolamine Hydroxylamine derivative Urea	61790-31-6 7664-41-7 1336-21-6 112-84-5 141-43-5 NA 57-13-6
Aromatic esters	Dicyclohexyl phthalate Ethyl 4-dimethylaminobenzoate	84-61-7 10287-53-5
Aromatic ketones	2-Benzyl-2-(dimethylamino)-4'-morpholinobutyrophenone 1-Hydroxycyclohexyl phenyl ketone 2-Hydroxy-2-methylpropiophenone 2-Isopropylthioxanthone 4-Isopropylthioxanthone 2-Methyl-4'-(methylthio)-2-morpholinopropiophenone Thioxanthone derivative[c]	119313-12-1 947-19-3 7473-98-5 5495-84-1 83846-86-0 71868-10-5 NA
Ethylene glycol ethers	Alcohols, C11-15-secondary, ethoxylated Butyl carbitol Ethoxylated tetramethyldecyndiol Ethyl carbitol Polyethylene glycol	68131-40-8 112-34-5 9014-85-1 111-90-0 25322-68-3

Category	Chemicals in category	CAS number
Hydrocarbons — high molecular weight	Distillates (petroleum), hydrotreated light Distillates (petroleum), solvent-refined light paraffinic Mineral oil Paraffin wax	64742-47-8 64741-89-5 8012-95-1 8002-74-2
Hydrocarbons — low molecular weight	n-Heptane Solvent naphtha (petroleum), light aliphatic Styrene	142-82-5 64742-89-8 100-42-5
Inorganics	Barium Kaolin Silica	7440-39-3 1332-58-7 7631-86-9
Olefin polymers	Polyethylene Polytetrafluoroethylene	9002-88-4 9002-84-0
Organic acids or salts	Citric acid Dioctyl sulfosuccinate, sodium salt Methylenedisalicylic acid	77-92-9 577-11-7 27496-82-8
Organophos-phorus compounds	Diphenyl (2,4,6-trimethylbenzoyl) phosphine oxide 2-Ethylhexyl diphenyl phosphate Phosphine oxide, bis(2,6-dimethoxybenzoyl) (2,4,4-trimethylpentyl)-	75980-60-8 1241-94-7 145052-34-2
Organotitanium compounds	Isopropoxyethoxytitanium bis(acetylacetonate) Titanium diisopropoxide bis(2,4-pentanedionate) Titanium isopropoxide	68586-02-7 17927-72-9 546-68-9
Pigments — inorganic	C.I. Pigment White 6 C.I. Pigment White 7	13463-67-7 1314-98-3
Pigments — organic	C.I. Pigment Blue 61 C.I. Pigment Red 23 C.I. Pigment Red 269 C.I. Pigment Violet 23 C.I. Pigment Yellow 14 C.I. Pigment Yellow 74	1324-76-1 6471-49-4 67990-05-0 6358-30-1 5468-75-7 6358-31-2
Pigments — organometallic	C.I. Basic Violet 1, molybdatephosphate C.I. Basic Violet 1, molybdate-tungstatephosphate C.I. Pigment Blue 15 C.I. Pigment Green 7 C.I. Pigment Red 48, barium salt (1:1) C.I. Pigment Red 48, calcium salt (1:1) C.I. Pigment Red 52, calcium salt (1:1) C.I. Pigment Violet 27 D&C Red No. 7	67989-22-4 1325-82-2 147-14-8 1328-53-6 7585-41-3 7023-61-2 17852-99-2 12237-62-6 5281-04-9
Polyol derivatives	Nitrocellulose Polyol derivative A[c]	9004-70-0 —[b]
Propylene glycol ethers	Dipropylene glycol methyl ether Propylene glycol methyl ether Propylene glycol propyl ether	34590-94-8 107-98-2 1569-01-3

Category	Chemicals in category	CAS number
Resins	Fatty acid, dimer-based polyamide[c]	NA
	Fatty acids, C18-unsatd., dimers, polymers with ethylenediamine, hexamethylenediamine, and propionic acid	67989-30-4
	Resin acids, hydrogenated, methyl esters	8050-15-5
	Resin, acrylic[c]	NA
	Resin, miscellaneous[c]	NA
	Rosin, fumarated, polymer with diethylene glycol and pentaerythritol	68152-50-1
	Rosin, fumarated, polymer with pentaerythritol, 2-propenoic acid, ethenylbenzene, and (1-methylethylenyl)benzene[c]	NA
	Rosin, polymerized	65997-05-9
Siloxanes	Silanamine, 1,1,1-trimethyl-N-(trimethylsilyl)-, hydrolysis products with silica	68909-20-6
	Silicone oil	63148-62-9
	Siloxanes and silicones, di-Me, 3-hydroxypropyl Me, ethers with polyethylene glycol acetate	70914-12-4

[a] No data or information available.
[b] Actual chemical name is confidential business information.
[c] Some structural information is given for these chemicals. For polymers, the submitter has supplied the number average molecular weight and degree of functionality. The physical property data are estimated from this information.

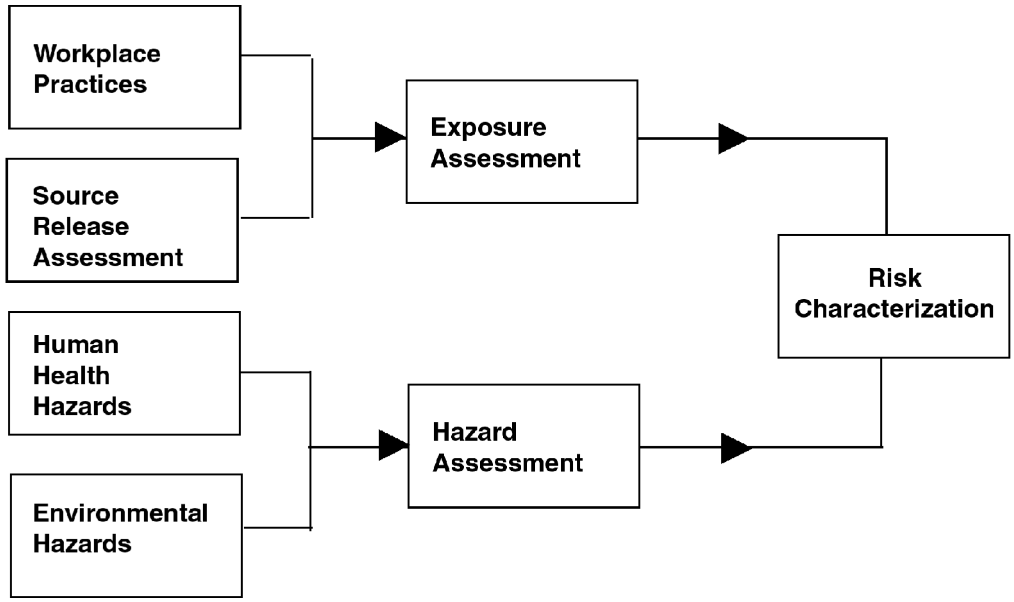
The CTSA Risk Assessment Methodology

A risk assessment has several phases: hazard identification, dose-response assessment, exposure assessment, and risk characterization. The CTSA risk assessment (Figure ES.3) focused on two areas of interest regarding the chemicals:

- possible health concerns to industry workers and the general population, and
- environmental concerns, including ambient air releases and aquatic toxicity.

For flexographic workers, exposures were analyzed for prep room workers and press workers, since both of these groups handle inks regularly in the course of their jobs. The assessment included exposure to VOCs and hazardous air pollutants (HAPs) through fugitive releases, which escape from the printing process into the ambient internal air and eventually exit the facility through windows and doors. Workers therefore can be exposed to fugitive emissions in the facility.

Figure ES.3 The Flexographic Inks CTSA Risk Assessment Process



Exposure was "modeled" — that is, it was not based on actual measurements of releases. A number of assumptions were made about a hypothetical "model facility" in developing the risk assessment. Most of the assumptions reflect typical operating conditions, and some facilitated identification of cleaner technologies or comparative analysis. Facilities with different operating characteristics would have different findings. Some of the assumptions include the following:

- 30% of volatile compounds released to air would be uncaptured emissions, and 70% would be stack emissions.
- Solvent-based ink systems would have a catalytic oxidizer with a 95% destruction efficiency.
- Press and prep-room workers would work a 7.5 hour shift, 250 days/year.
- Press and prep room workers would have routine two-hand contact (no gloves) with ink unless a substance was corrosive.
- Press speed would be 500 feet per minute.

In addition, the exposure estimates used for dermal contact were "bounding" estimates, which provide an upper and lower limit of exposure. The inhalation exposure estimates are considered "what-if" estimates because their probability of occurrence is not known.

The risk analysis used published studies of hazards and toxicity associated with each chemical, where available. When published studies were not available, EPA's Structure Activity Team (SAT) determined hazard levels based on analog data and/or structure activity considerations, in which characteristics of the chemicals were estimated in part based on similarities with chemicals that have been studied more thoroughly. Many chemicals in flexographic inks have not been studied thoroughly for environmental effects or health concerns. Chemicals in UV-cured inks, perhaps because they are newer, are much less likely than solvent- and water-based chemicals to have undergone in-depth testing.

Concerns posed by any ink system will vary depending upon many factors, such as the specific chemicals in the inks, how the inks are handled and used, the type of toxicity (systemic or developmental), and the exposure route (inhalation or dermal).

How the CTSA Defined Risk Levels

Each chemical substance evaluated was designated as having a "clear," "potential," or "low" concern for risk (Table ES.2). *Clear concern for risk* indicates that for the chemical in question, under the assumed exposure conditions of the Flexographic inks CTSA research, adverse effects were predicted to occur. *Potential concern for risk* indicates that for the chemical in question, under the assumed exposure conditions, adverse effects may occur. *Low or negligible concern for risk* indicates that for the chemical in question, under the assumed exposure conditions, no adverse effects were expected.

Table ES.2 Criteria for Risk Levels

Level of Concern for Risk	Hazard Quotient [a]	Margin of Exposure [b]		SAT Hazard Rating [c]
		NOAEL	LOAEL	
Clear	> 10	1 to 10	1 to 100	moderate or high
Potential	1 to 10	> 10 to 100	> 100 to 1,000	low-moderate
Low or negligible	< 1	> 100	> 1,000	low

[a] Hazard Quotient (HQ) is the ratio of the average daily dose (ADD) to the Reference Dose (RfD) or Reference Concentration (RfC), where RfD and RfC are defined as the lowest daily human exposure that is likely to be without appreciable risk of non-cancer toxic effects during a lifetime. The more the HQ exceeds 1, the greater the level of concern. HQ values below 1 imply that adverse effects are not likely to occur.

[B] NOAEL = No Observed Adverse Effect Level. LOAEL = Lowest Observed Adverse Effect Level. A Margin of Exposure (MOE) is calculated when a RfD or RfC is not available. It is the ratio of the NOAEL or LOAEL of a chemical to the estimated human dose or exposure level. The NOAEL is the level at which no significant adverse effects are observed. The LOAEL is the lowest concentration at which adverse effects are observed. The MOE indicates the magnitude by which the NOAEL or LOAEL exceeds the estimated human dose or exposure level. High MOE values (e.g., greater than 100 for a NOAEL-based MOE or greater than 1,000 for a LOAEL-based MOE) imply a low level of risk. As the MOE decreases, the level of risk increases.

[C] This column presents the level of risk concern if exposure is expected. If exposure is not expected, the level of risk concern is assumed to be low or negligible. SAT-based systemic toxicity concerns were ranked according to the following criteria: high concern — evidence of adverse effects in humans, or conclusive evidence of severe effects in animal studies; moderate concern — suggestive evidence of toxic effects in animals; or close structural, functional, and/or mechanistic analogy to chemicals with known toxicity; low concern — chemicals not meeting the above criteria.

Human Health Findings

The toxicity information was combined with estimated releases and exposures to develop a risk characterization of individual chemical substances. Each chemical substance was analyzed for systemic and developmental toxicity. *Systemic toxicity* means adverse effects on any organ system following absorption and distribution of a chemical throughout the body. *Developmental toxicity* refers to adverse effects on a developing organism that may result from as little as a single exposure prior to conception, during prenatal development, or postnatally up to the time of sexual maturation. The major manifestations of developmental toxicity are death, structural abnormality, altered growth, or functional deficiency. Although some inks in the CTSA also contained known or possible human carcinogens, there was not enough quantitative information to analyze specific cancer risk concerns.

Worker Health Risks

The study assessed possible risks via both the inhalation and dermal (skin) pathways. Each ink system contained chemicals that showed clear health risk concerns for workers who handle inks in the prep room or pressroom, under the assumptions used for the study.

Of the roughly 100 chemicals studied, 24 were found to pose *clear* worker health risk concerns (Tables ES.3 and ES.4).[***]

- Alcohols, amides and nitrogenous compounds, and acrylated polyols contained the most chemicals found to pose clear worker risk concerns.
- For pressroom workers, exposure was highest with solvent-based inks because of the higher air release rate.
- In the three *solvent-based* ink product lines studied, most of the chemicals presenting a clear occupational risk concern were solvents. Pressroom workers can be exposed to uncaptured (i.e., fugitive) emissions in the facility, while stack emissions from using solvent-based inks are destroyed by oxidizers. The use of oxidizers thus only impacts stack emissions and does not reduce occupational health hazards and risk concerns.
- In *water-based* formulations, amides or nitrogenous compounds often presented systemic risk concerns.
- The use of press-side solvents and additives increased the occupational risk concern for many of the solvent- and water-based ink formulations. In particular, alcohols and propylene glycol ethers in solvent-based inks, and amides and nitrogenous compounds, alcohols, and ethylene glycol ethers in water-based inks presented clear or potential occupational risk concerns in certain formulations.
- For *UV-cured* inks, some acrylated polyols and amides or nitrogenous compounds showed clear inhalation risk concerns for workers. It is important to understand, however, that the CTSA studied *uncured* UV inks only, due to resource limitations. The concerns associated with *cured* UV inks are not known, but anecdotal information from industry suggests that curing may greatly reduce such concerns.

[***] To protect manufacturers' proprietary information, when discussing formulations the risk results group the specific chemicals into categories rather than presenting results for individual chemicals.

Table ES.3 Clear INHALATION Risk Concerns for Flexographic Workers

Ink System	Chemical Categories with Chemicals of Clear Risk Concern	Systemic Risk Concern	Developmental Risk Concern
Solvent-based	Alcohols	X	X
	Alkyl acetates	X	
	Hydrocarbons (low molecular weight)	X	
	Propylene glycol ethers	X	
Water-based	Alcohols	X	
	Amides or nitrogenous compounds	X	X
	Ethylene glycol ethers	X	
UV-cured	Acrylated polyols	X	X
	Amides or nitrogenous compounds	X	X

Table ES.4 Clear DERMAL Risk Concerns for Flexographic Workers

Ink System	Chemical Categories with Chemicals of Clear Risk Concern	Systemic Risk Concern	Developmental Risk Concern
Solvent-based	Alcohols	X	X
	Alkyl acetates	X	
	Inorganics	X	X
	Organometallic pigments		X
	Organotitanium compounds		X
	Organic acids or salts		X
	Propylene glycol ethers	X	
Water-based	Alcohols	X	X
	Amides or nitrogenous compounds	X	X
	Ethylene glycol ethers	X	
	Organic pigments	X	
	Organometallic pigments	X	
UV-cured	Acrylated polyols	X	X
	Acrylated polymers	X	X
	Amides or nitrogenous compounds	X	X
	Inorganic pigments		X
	Organometallic pigments	X	
	Organophosphorus compounds	X	

Table ES.5 lists the potential effects on organ systems (e.g., cardiac, respiratory, reproductive) from dermal and inhalation exposure to chemicals and chemical categories of clear worker health risk concern. “Toxicological endpoints” are the *potential* effects on organ systems that have been reported in the medical literature and other scientific reports in association with use of a chemical. This does not mean, however, that any of these effects are necessarily *caused by* that chemical. Only the chemicals listed for a specific category were associated with clear worker risk concerns. Thus, for example, CI Pigment Red 23 was the only organic pigment that showed clear worker health risk concerns. A number of the ink chemical categories that were examined in the study (e.g., resins, olefin polymers, siloxanes) did not show clear risk concerns and thus are not included in this table.

Table ES.5 Toxicological Endpoints of CTSA Chemicals with CLEAR Worker Health Risk Concerns

Chemical Category	Chemical	Potential Effects on Organ Systems (via oral and dermal paths) [d]
Acrylated polymers	Glycerol propoxylate triacrylate	tissue necrosis at application site, decreased body weight, neurotoxic and respiratory effects
Acrylated polyols	Dipropylene glycol diacrylate (SAT)[a]	genotoxicity, neurotoxicity, oncogenicity, developmental and reproductive effects, dermal and respiratory sensitization, and skin and eye irritation
	1,6-Hexanediol diacrylate	developmental effects
	Hydroxypropyl acrylate	respiratory effects
	Trimethylolpropane triacrylate	decreased body weight, skin and neurotoxic effects, changes in clinical chemistry, altered organ weights, respiratory effects
Alcohols	Ethanol	blood, liver, neurotoxic, and reproductive effects, decreased cellularity of the spleen, thymus, and bone marrow; dev: fetal malformations
	Isobutanol	blood and neurotoxic effects, changes in enzyme levels; dev: cardiac septal defects
	Isopropanol	blood and skin effects, tissue necrosis at application site, increased kidney and liver weight; liver, neurotoxic, reproductive, respiratory, and spleen effects, changes in enzyme levels and clinical and urine chemistry; dev: fetal death, musculoskeletal abnormalities, fetotoxicity
Alkyl acetates	Butyl acetate	changes in serum chemistry, fluctuations in blood pressure; dev: fetotoxicity, musculoskeletal abnormalities
	Ethyl acetate	blood, cardiovascular, gastrointestinal, kidney, liver, neurotoxic, and respiratory effects, decreased spleen and liver weight, increased adrenal, lung, and kidney weight
Amides or nitrogenous compounds	Ammonia	corneal, liver, respiratory, and spleen effects
	Ammonium hydroxide	eye effects, nasal irritation, respiratory effects
	Ethanolamine	respiratory irritation; kidney, liver, neurotoxic, and respiratory effects
	Hydroxylamine derivative (SAT) [a]	genotoxicity, dermal sensitization, developmental toxicity

Chemical Category	Chemical	Potential Effects on Organ Systems (via oral and dermal paths) [d]
Ethylene glycol ethers	Butyl carbitol	blood and skin effect, liver effects
	Alcohols, C11-C15-secondary, ethoxylated (SAT)[a]	skin irritant; eye irritation and lung effects
	Ethyl carbitol	no data
Hydrocarbons — low molecular weight	n-Heptane	auditory and neurotoxic effects, altered serum chemistry
Inorganics	Barium	decreased body weight, reproductive and respiratory effects, increased arterial blood pressure; dev: decreased survival and weight gain, changes in hematology parameters
Organic acids or salts	Dioctyl sulfosuccinate, sodium salt	no data
Organo-phosphorous compounds	Phosphine oxide, bis(2,6-dimethoxybenzoyl) (2,4,4-trimethylpentyl)-	no data
Organotitanium compounds	Isopropoxyethoxytitanium bis(acetylacetonate) (SAT)[a]	neurotoxicity, genotoxicity, oncotoxicity, and developmental/ reproductive toxicity; skin, eye, mucous membrane irritant
	Titanium diisopropoxide bis(2,4-pentanedionate)	SAT: irritation of the eyes, skin, and mucous membranes. Moderate concern based on release of hydrolysis products: 2,4 pentanedione, inorganic titanium, and isopropanol. 2,4 pentanedione: concern for neurotoxicity, mutagenicity, oncogenicity, and developmental/reproductive toxicity. Inorganic titanium: concern for mutagenicity and oncogenicity. Isopropanol: concern for liver, neurotoxic, reproductive, respiratory, and spleen effects; changes in enzyme levels and clinical and urine chemistry; fetal death, musculoskeletal abnormalities, fetotoxicity, blood and skin effects, tissue necrosis at application site, increased kidney and liver weight
	Titanium isopropoxide	SAT: irritation of the eyes, skin, and mucous membranes. Moderate concern based on release of the hydrolysis products, inorganic titanium and isopropanol. Inorganic titanium: concern for mutagenicity and oncogenicity. Isopropanol: concern for liver, neurotoxic, reproductive, respiratory, and spleen effects; changes in enzyme levels and clinical and urine chemistry; fetal death, musculoskeletal abnormalities, fetotoxicity, blood and skin effects, tissue necrosis at application site, increased kidney and liver weight.
Pigments — organic	CI Pigment Red 23	no data
Pigments — organometallic	D&C Red No. 7	no data

Chemical Category	Chemical	Potential Effects on Organ Systems (via oral and dermal paths) [d]
Propylene glycol ethers	Propylene glycol methyl ether	increased mortality; blood, neurotoxic, and skin effects; altered kidney weights; decreased growth, liver, neurotoxic, reproductive, and respiratory effects, increased liver and kidney weights; dev: delayed ossification of vertebrae, musculoskeletal abnormalities

These chemical categories posed risk concerns under the specific conditions of this study; they might be associated with different risks, or with no risk at all, under different conditions.
Dev = developmental effects. All endpoints not specifically indicated as developmental are systemic.
[a] SAT: Structure Activity Team and acute data reports.
[d] Developmental risks for SAT-evaluated chemicals were evaluated on a “concern/no concern” basis.

Many of the chemical substances that show hazard or risk concern are commonly used in flexographic inks, although they are not necessarily found in every ink formulation. To protect workers from such concerns, printing firms can take several steps:

- Review ink formulations against CTSA data, MSDS information, Table 8.13 of the Flexographic Inks CTSA, and other sources to identify chemicals that may present concerns under certain conditions of use.
- Establish effective policies that require workers to wear proper gloves and other personal protective gear when working with inks. If workers wear appropriate protections, the dermal concern is essentially zero.
- Ensure appropriate ventilation to minimize inhalation exposure.
- Adopt pollution prevention practices to minimize use and disposal of chemicals of concern (e.g., management of chemical inventory).

General Population Risks

For the general population (people who live near a printing facility), the study assessed possible inhalation risks. No chemical categories showed a clear risk concern to the general population. However, alcohols in solvent- and water-based inks, and acrylated polyols in UV-cured inks, included one or more chemicals that showed a *potential* risk concern for the general population. Exposures and risk concerns for the general population due to emissions from water-based and UV-cured inks were calculated to be significantly lower than those of solvent-based inks. This is because solvent-based inks showed higher *fugitive* emissions (e.g., chemicals released from a long web run between presses), which outweighed the decrease in stack emissions resulting from the use of oxidizers.

Environmental Findings

Ambient Air Releases

Releases to air result from the evaporation of chemicals during the flexographic printing process. Releases to air are used to estimate inhalation exposure to particular chemicals for workers and the general population. The CTSA examined two forms of air releases. Stack emissions are collected from the press and are released through a roof vent or stack to the outside air, sometimes undergoing treatment to reduce the emissions. Fugitive emissions escape from the printing process (e.g., from a long web run between presses), and exit the facility through windows and doors. It was assumed that 30% of the VOCs released to the air were fugitive emissions, and 70% were captured by the press system and released through a stack. It was also assumed that solvent-based ink releases would pass through a catalytic oxidizer with a destruction efficiency of 95%, but that water-based or UV-cured ink systems would not utilize an oxidizer. Environmental releases relate to the rates of vapor generation, which vary depending on press speed, VOC content of the ink mixture, equipment operating time, temperature of the ambient air and ink system, the capture efficiency of the press system, and the destruction efficiency of the air control devices.

The calculated volatilization rates of the solvent-based inks were considerably higher than those for the other two ink systems. The volatilization rates for water-based inks were considerably lower than those for solvent-based inks, but the stack releases were higher because the use of an oxidizer was not anticipated. On the other hand, the fugitive emissions of the water-based inks were considerably lower than those for solvent-based inks because of the lower average VOC content of water-based inks.

The UV-cured inks showed releases comparable to those of water-based inks and higher than those of solvent-based inks. These figures were calculated with the assumption that all VOCs would be released to the air. In reality, however, much of the volatile content would be incorporated into the coating during the UV curing process. The decrease in emissions under real-world conditions is unknown.

Adding solvents, reducers, extenders, cross-linkers, and other compounds to the inks increased their volatile content, resulting in greater environmental releases. During the CTSA performance demonstrations, solvents were added in higher quantities to solvent-based ink formulations than to water-based and UV-cured formulations, which further increased the releases from solvent-based inks.

Press speed greatly affected the amount of ink consumed, and thus the releases of volatile compounds. Air releases also varied among colors within each ink system; the differences were primarily due to different ink consumption rates, which will vary with every printing job.

Aquatic Toxicity
Roughly half of the ink chemicals showed a medium or high aquatic toxicity (capable of causing long-term effects to aquatic organisms, in a concentration of less than 0.1 mg/liter). Eighteen chemicals (Table ES.6) were found to have high aquatic toxicity. Another 35 chemicals showed medium aquatic toxicity. Because the inks were not expected to be released to the aquatic environment, water releases and subsequently related risks were not assessed. If any of these inks are in fact released untreated to water, however, there could be aquatic risk concern.

Table ES.6 CTSA Chemicals With High Aquatic Toxicity

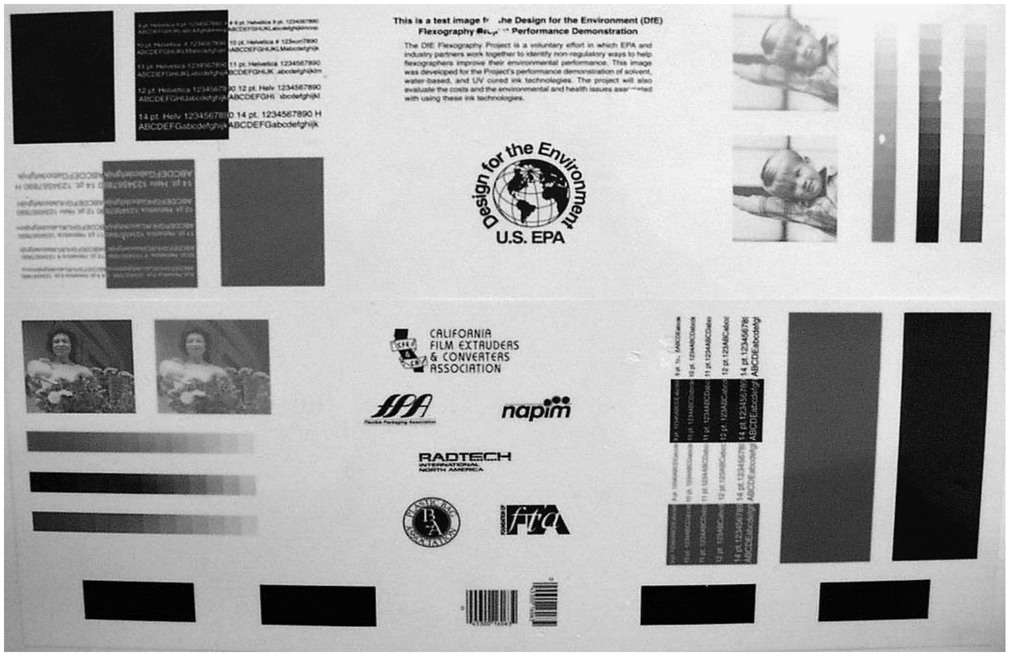
Amides, tallow, hydrogenated	n-Heptane
Ammonia	2-Isopropylthioxanthone
C.I. Basic Violet 1 molybdatephosphate	4-Isopropylthioxanthone
C.I. Basic Violet 1 molybdatetungstatephosphate	Mineral oil
C.I. Pigment Violet 27	Resin acids, hydrogenated, methyl esters
Dicyclohexyl phthalate	Styrene
Distillates, petroleum, hydrotreated light	Thioxanthone derivative
2-Ethylhexyl diphenyl phosphate	Trimethylolpropane ethoxylate triacrylate
Glycerol propoxylate triacrylate	

PERFORMANCE

Because quality of printing is a critical need of flexographers, the CTSA conducted 18 performance tests, which examined quality aspects anticipated to be important for a broad range of flexographic printers. (See Chapter 4 for details.)

Eleven *performance demonstrations* were conducted at printing facilities that volunteered to participate, using inks donated by ink companies. The inks used were considered fairly representative of ink types commonly in use at that time. Five ink colors (cyan, magenta, blue, green, and white) were included, to allow testing of both process and line printing results. The performance demonstrations were brief printing runs of a representative test image (Figure ES.4), which was printed using wide-web presses onto three types of film substrates: oriented polypropylene (OPP); low-density polyethylene (LDPE); and polyethylene/ethyl vinyl acetate co-extruded film (PE/EVA). These substrates were chosen because they correspond to important flexographic market segments. To collect baseline data, *laboratory runs* were also conducted in the printing laboratory of Western Michigan University. This was done to give printers a better sense of the actual capabilities of the ink-substrate combinations.

Figure ES.4 Test Image Used in Demonstration Runs



Performance tests were conducted on the samples from both the performance demonstrations and the laboratory runs (Table ES.7).

Table ES.7 Performance Tests Conducted in CTSA

Adhesive lamination	Ice water crinkle adhesion
Block resistance	Image analysis
CIE L*a*b*	Jar odor
Coating weight	Mottle/lay
Coefficient of friction (COF)	Opacity
Density	Rub resistance
Dimensional stability	Tape adhesiveness
Gloss	Trap
Heat resistance/heat seal	Uncured residue (UV-cured inks only)

Performance Findings

The quality of performance varied widely across ink systems, substrates, and ink formulations. No clear evidence emerged that any one ink system performed best overall. For example,

- Water-based inks outperformed solvent-based inks on both LDPE and PE/EVA substrates. Solvent-based inks performed better than water-based inks on the adhesive lamination test.
- Gloss was highest for solvent-based inks on PE/EVA. Gloss was low on UV-cured inks, despite the fact that high gloss is considered to be a strength of UV finishes.
- Odors varied in both strength and type across both ink and substrate type.
- Mottle was significantly higher for water-based inks, as well as for blue inks overall.
- UV-cured inks displayed good resistance to blocking, particularly on PE/EVA and no-slip LDPE.
- UV-cured inks displayed relatively good trapping.
- Mottle results for UV-cured inks were better than that of the water-based inks and comparable to that of the solvent-based inks.
- Coating weight was greater for UV-cured inks, despite lower ink consumption.
- Some UV-cured inks showed unimpressive results on the rub resistance and tape adhesiveness tests.

The variances in results show the importance of a number of factors in the performance of these inks:

- Substrate type
- Type and amount of vehicle (e.g., solvent in solvent-based ink and water in water-based ink), as well as press-side solvents and additives
- Functional ink-substrate interactions such as wetting and adhesion

Table ES.8 lists the ink system, color, and substrate combinations showing “best in class” performance for selected tests that were run. Most of these tests do not have industry standards, and for some tests the determination of a better or worse result can depend on the needs of a specific printing situation. (The “worst” score is also provided, but only to give an indication of the large range in scores on almost all tests.) Due to a variety of issues that occurred at volunteer facilities, not all ink systems received all tests.

Table ES.8 Selected "Best in Class" Performances on Flexography CTSA Tests

Test	Best Score	Ink System	Substrate	Color	Worst Scoreb[a]
Adhesive lamination	.3040 kg (highest)	solvent[b]	OPP	N/A[c]	.2575 kg (lowest)
Block resistance	1.0 (lowest)	UV no slip	LDPE	N/A	3.2 (highest)
Density	2.17 (highest)	UV high slip	LDPE	blue	1.09 (lowest)
Gloss	59.08 (highest)	solvent	PE/EVA	N/A	32.31 (lowest)
Heat resistance	0 failures (lowest)	solvent[b]	OPP	N/A	24 failures (most)
Ice water crinkle	no ink removal (least)	solvent, water	LDPE, PE/EVA	N/A	30% ink removal (most)
Image analysis	324 μm^2 dot area (lowest)	solvent	PE/EVA	cyan	1050 μm^2 (highest)
Mottle	47 (lowest)	UV no slip	LDPE	green	812 (highest)
Rub resistance, wet	0 failures at 10 strokes	water, solvent	LDPE (PE/EVA)	N/A	failure at 2.2 strokes

[a]This score represents the opposite end of the range of all scores received on this test for all ink systems tested.
[b]UV-cured samples were not tested.
[c]N/A indicates that the test results were not color-specific.

These performance demonstrations were completed in 1997, since which time flexographic printing technology for UV-cured inks has made significant advances. The test results of this CTSA provide a snapshot of UV technology early in its technical development but do not necessarily lead to any conclusions about current or potential abilities of UV inks. In fact, just as for solvent-based and water-based inks, no one test can provide a reliable or accurate indicator of overall quality for any printer. Printers need to consider a variety of different factors in determining acceptable quality. These factors — among them cost, health and environmental risks, energy use, and pollution prevention opportunities — are discussed in other chapters of this CTSA.

In addition, because performance is a function of many factors — including equipment, ink, substrate, and operator experience — a printing facility that conducts its own performance tests might obtain different results than the CTSA. This potential for variability is demonstrated by the performance results, which differed widely among formulations within the same ink system. The performance variability indicates that there may not be one best overall choice of an ink system for all performance conditions and applications. A flexographic printer cannot simply assume that one ink system or ink-substrate combination will be best-suited to the firm's overall needs. Careful testing of a potential ink system on the various substrates that a printer will be using most often is critical to obtaining desired quality on a consistent basis.

UV curing technology, especially as it pertains to wide-web printing on film substrates, was in a developmental stage at the time these tests were conducted. The test results in this CTSA provide a snapshot of UV technology early in its technical development but do not necessarily lead to any conclusions about current or potential abilities of UV-cured inks. Since that time, improvements to this ink system have been made on several fronts. In addition, manufacturers of both solvent-based and water-based inks have made improvements in formulations since the performance demonstrations were completed. In particular, changes that have been made to resins and slip additives of inks may yield improved adhesive characteristics and other traits.

COSTS

A number of costs are important to facility profitability and have the potential to highlight differences among ink systems. The study evaluated the costs of materials (ink and press-side additions), labor, capital, and energy. Substrate costs were not evaluated because they are not dependent upon ink use. Input quantities for materials were obtained during the performance demonstrations. Suppliers provided information about costs.

This analysis averages industry information, and therefore it may not reflect the actual experience of any given printing facility in this short-term demonstration. For example, the efficiencies of a long run with familiar products were not achieved. Also, press speed under many printing conditions is expected to be different (and in general, higher) than in this analysis. While this study focused on those costs that typically account for the majority of total costs, other important costs (e.g., waste disposal, regulatory compliance, insurance, storage, clean-up, and permitting) should not be overlooked. In addition, press maintenance and other conditions may affect ink usage, and therefore ink costs.

Cost Findings

Highlights of the cost analysis include the following:

- Materials were the highest cost category for the CTSA printers among the categories studied. Water-based inks had the lowest material costs of the three systems, showing a higher mileage than solvent-based inks and a much lower per-pound cost than UV-cured inks.
- The analysis did not consider start-up and clean-up labor, and the press speed was assumed to be the same for all three ink systems. (Labor costs would have differed by ink system if the analysis had captured the costs of preparation, cleanup, etc.) Therefore, *labor cost* (wages and benefits for two press operators) was identical in the study for all three systems.
- *Energy cost* (electricity and natural gas) was highest for UV-cured inks. The water-based system showed the lowest energy cost because it assumed no energy use by oxidizers. If oxidizers were to be used, much of the water-based system's cost advantage would disappear.
- Water-based inks had the lowest *capital costs* (press and other required components), because the water-based printers did not use oxidizers. Solvent-based inks showed higher capital costs because of the expense of oxidizers. Because UV uses lamps to cure inks, this system also had higher capital costs. However, the capital costs of a new press for all three technologies were relatively similar. Therefore, they are likely to be only a small factor in the selection of an ink system.
- Assuming a press speed of 500 feet per minute, the CTSA found that the *total cost* was lowest for the water-based system, with the solvent-based and UV-cured systems costing on average 24% and 38% more respectively (Table ES.9).

Table ES.9 Cost Averages (per 6,000 square feet, at 500 feet per minute)

Ink system	Materials (Ink & Additions)	Labor	Energ y	Capital	Total
Solvent-based	$15.29	$5.29	$0.53	$11.87	$32.98
Water-based	$9.55	$5.29	$0.35	$11.41	$26.60
UV-cured	$18.63	$5.29	$1.03	$11.87	$36.82

Generally speaking, press speed appears to be the most important driver of a printer's total cost, because all costs except that of ink and substrate were impacted by press speed. Thus, press speed is a critical variable in maximizing profitability of flexographic printing, Therefore, if a facility can run one ink system (or one formulation) notably faster than another while meeting product quality standards, the faster system or formulation will probably also be the most cost-effective system.

RESOURCE USE AND ENERGY CONSERVATION

By minimizing resource and energy use, printers can improve both their bottom line and the environment. To identify potential issues on which printers may wish to focus their efforts, the study investigated several sources of resource consumption (Table ES.10) and pollutant generation related to the three ink systems studied:

- resources consumed,
- energy used,
- energy-related emissions generated by each ink system, and
- possible environmental impacts of energy-related impacts.

Table ES.10 Categories of Consumption Studied

Category of Consumption	Specific elements Included	Comments
Printing-related resources	Inks, solvents, and press-side additives	The *ink consumption* figures were calculated during the performance demonstrations, and were affected by several site-specific factors, such as type of cleaning equipment, anilox roll size, and the level of surface tension of the substrate.
Energy consumed by the printing of each ink-substrate combination	Natural gas and electricity to run presses presses and ancillary press equipment (oxidizers, hot air dryers, drying ovens, corona treaters, UV-curing lamps and coolers)	Equipment vendors estimated energy requirements in kilowatts for electricity and in Btus/hr for natural gas. These estimates were used instead of actual site-specific data to calculate energy consumption for the study.

The energy-related emissions from printing each ink-substrate combination include carbon dioxide, carbon monoxide, hydrocarbons, nitrogen oxides, particulate matter, dissolved solids, solid wastes, sulfur oxides, and sulfuric acid. With natural gas, the emissions are generated at the printing facility, but with electricity, the emissions are generated off-site at the power plant. Either way, the printing facility needs to know environmental impacts that can be attributed to the printing processes used. This allows a facility to plan ways to reduce energy use and the related environmental releases that are generated by different types of energy. Employing more energy-efficient technologies may benefit printers by reducing production costs, lowering energy-related emissions, and improving the facility's public image.

Resources Used and Emissions Generated

The study examined various specific inputs to the printing processes, including the press units, oxidizers, hot air dryers, drying ovens, corona treaters, UV-curing lamps, and coolers. When all of these were taken into consideration,

- The energy consumed was estimated to be lowest for the water-based system because no oxidizers or curing lamps were used. The solvent-based system, which used oxidizers to destroy stack emissions, consumed the most energy.
- The estimated emissions were lowest for the water-based system, because much of its energy derives from natural gas, which releases less emissions per unit of energy than does electricity. Although the UV-cured system consumed little more energy than the water-based system, it was estimated to result in the highest total energy-related emissions, because all of its energy comes from electricity.

Table ES.12 lists the amounts of resources consumed by each ink system, as well as the amounts of environmental releases of pollutants associated with energy production. Results are reported in terms of grams per 6000 square feet of substrate, which allows a direct comparison of pollutants generated by the different ink systems.

Table ES.11 Average Resource Use and Energy-Related Emissions (at 500 fpm)

Ink System	Resources Consumed [a] (lb/6,000 ft^2)	Energy Consumed per 6,000 ft^2 (Btu) [b, c]	Energy-Related Emissions Generated (g/6000 ft^2)[d]
Solvent-based	8.53	100,000	10,000
Water-based	4.14	73,000	6,800
UV-cured	2.16	78,000	18,000

[a] Ink consumption figures were averaged from the total costs of ink, solvents, and additives for all three substrates in Table 6.4; energy consumption figures are from Table 6.11; and energy-related emissions are from Table 6.21.

[b] Electrical energy was converted to Btus using the factor of 3,413 Btu per kW-hr.

[C] Electricity was generated offsite.

[d] Energy-related emissions were calculated using a computer model rather than by capturing and analyzing actual emissions from the facilities.

Pollutants that were released during energy production of the CTSA printing runs include carbon dioxide, carbon monoxide, dissolved solids, hydrocarbons, nitrogen oxides, particulate matter, solid wastes, sulfur oxides, and sulfuric acid. Again, because UV curing relies exclusively upon electricity, this ink system was shown to generate more of the pollutants that are associated with this form of energy (such as nitrogen oxides, carbon dioxide, and sulfur oxides), some of which affect environmental air quality and are important to global climate change. Energy use was analyzed using the methodology press speed (500 feet per minute) and actual press speed. The amount of pollutants generated was associated with press speed, and higher press speed produced fewer grams of pollutants for the same number of feet of substrate.

Overall, the water-based ink system generated the fewest grams of pollutants per 6000 feet of substrate printed, and the UV-cured ink system generated the most. Most of these pollutants fall into a category called "use impairment impacts," which includes global warming compounds, acid rain precursors, smog formers, corrosives, dissolved solids, odorants, and particulates.

CHOOSING AMONG FLEXOGRAPHIC INKS

This section summarizes important findings of the Flexographic Inks CTSA by ink system, and identifies ways to use the CTSA to incorporate health and environmental impacts of flexographic ink chemicals in business decision-making.

Choosing an ink system, an ink product line (e.g., solvent-based ink #1), or a specific ink formulation (e.g., color within a product line, such as solvent-based ink #1 white) is not a simple task. The study found substantial variation within each ink system in health and environmental impacts, performance, cost, and resource use. Each aspect of ink use has implications — important environmental health and safety implications as well as performance, cost, and energy use . Every product line analyzed in the CTSA included chemicals that are associated with multiple clear health risk concerns for flexographic press workers (Table 8.3). Each ink system also was found to have safety hazards for the workplace (flammability, ignitability, reactivity, or corrosivity concerns). All of the formulations released VOCs and sometimes HAPs as well (Table 8.4).

Highlights of CTSA Findings

Solvent-based Inks

- The solvent-based ink system, on average, had total operating costs that were lower than those of UV-cured inks but higher than those of water-based inks. This higher cost can be attributed mostly to higher material and capital costs of solvent-based technologies. In particular, average material costs for solvent-based systems (per 6,000 square feet of image) were approximately $5.00 higher than those for water-based systems.
- The solvent-based system on average outperformed both water-based and UV-cured systems. This system was the best with respect to gloss and trap and among the best on the other three summary performance tests.
- On average, solvent-based inks contained two to four chemicals with a clear concern for occupational risk, slightly higher than the ranges for water-based and UV-cured inks. This may indicate a higher occupational risk.
- Public health risk was evaluated through releases of smog-related compounds, VOC and HAP content, and the systemic and developmental risks to the general population. Despite the fact that this system used oxidizers, emissions were calculated to be considerably higher than the emissions of the other systems. VOC content was, as expected, much higher than either of the two other systems. This system did not contain any HAPs. For general population risks, two chemical categories in one solvent based ink (ink #2) contained chemicals that presented a potential concern for risk.
- In terms of process safety, solvent-based inks had more concerns than the other systems, although the results for UV-cured inks were incomplete. Only solvent-based inks presented an ignitability concern; they also presented a higher flammability concern than water-based inks.
- Solvent-based inks were shown to use more energy to produce the same square footage of image.

Water-based Inks

- Operating costs were lowest for the water-based ink product lines. In fact, in all cost categories, water-based ink systems had the lowest average cost. Cost savings were particularly pronounced for material costs.
- Though water-based ink formulations #2 and #4 had the best mottle scores of all product lines, overall the water-based inks did not perform as well as the solvent-based inks in the five summary performance categories. The system also was outperformed by the UV-cured inks in three categories. While this may indicate a lower quality product, it is important to note that in many cases the differences were small and may be insignificant.
- In the occupational health area, water-based inks presented a lower average number of chemicals with a clear concern for risk per product line, indicating a better chance of reducing occupational health risks compared to solvent-based inks.
- The amount of smog-related emissions that resulted from ink releases and energy production with the water-based system was considerably lower than that from solvent-based system, and was comparable to that from the UV-cured system. Water-based inks had a much lower VOC content than solvent-based inks, but were

the only inks that contained HAPs.
- Like with solvent-based inks, printers often add VOC solvents and additives at press side to water-based inks. In substantial amounts, these materials compromise the low-VOC content of the ink and can pose clear pressroom worker risks. At one site using water-based inks (Site 3), over half of the emissions resulted from materials added at press-side.
- The safety of water-based inks was better than that of solvent-based inks. There was no indication of ignitability or reactivity. However, water-based inks had a higher flammability risk than UV-cured inks.
- As for energy expenditures, water-based inks had the lowest average energy use.

UV-cured Inks
- The UV-cured inks had the highest average operating costs. However, since it is a new developing technology for wide-web film, these costs are likely to fall as the technology develops. The biggest cost differential was the material costs, falling approximately \$8.00 per 6,000 ft^2 of image above the average costs for water-based inks. It is also worth noting that energy costs of the UV systems were considerably higher — nearly two times the cost for solvent-based inks and nearly three times the cost for water-based inks.
- The performance of the UV-cured inks was generally worse than that of solvent-based inks, though this system had better blocking resistance, and individual product lines had ice water crinkle and mottle results that were equal to the solvent-based results. The performance results were slightly better than those of the water-based inks.
- The UV-cured inks presented the lowest chance of occupational health risk, and with respect to public health, had the lowest HAP and VOC contents. A couple of SAT-analyzed compounds present a potential concern for general population risk, however, indicating that research on some compounds is needed.
- Safety hazard data were incomplete for UV inks. However, UV inks were the only inks that present the potential for reactivity.
- Finally, the energy used by UV-cured systems was approximately 22% less than that of solvent-based inks, and was only slightly higher than that of the water-based inks. The air releases associated with the energy production were higher than solvent-based inks, however, because all energy required by the UV system was derived from electricity — a more pollution-intensive energy source in comparison to natural gas.

Choosing Cleaner, Safer Ink Chemicals

Because of the importance of the specific formulation to the results of the flexographic ink study, printers are advised to pay as much attention to selecting the "cleanest" formulation within an ink system as to the ink system itself.

Table 3-1 provides toxicity and risk screening information on the chemical substances that were included in this study. Many of the substances were found in multiple ink formulations and are likely to be found in other inks. Whether choosing amongst the ink systems or choosing an ink formulation, it is important to consider the health, safety, and environmental impacts of the chemical substances that make up a formulated product. The DfE Flexographic Inks CTSA can serve as a first step in bringing a more positive environmental profile into the printing shop. The DfE Program encourages printers and the ink manufacturer and distributors to actively engage in a dialog on “getting the right mix” in the print shop.

Table 8.13 summarizes hazard and risk information for every chemical category and chemical in the study. Flexographic professionals can use this table to compare chemicals within and across chemical categories, which can help to identify possible alternatives for a chemical that shows concerns. As an example, Table ES.12 below shows a partial entry for ethylene glycol ethers from Table 8.13. The Hazard columns indicate that ethylene glycol ethers have moderate (M) and moderate-high (M-H) hazards, and the Occupational Risk column shows several instances of clear risk concern for this chemical category under the conditions of use analyzed in this study.

Table ES.12 Summary of Hazard and Risk Data by Chemical Category (Excerpt)

Ink System	Chemicals	Data Source	Hazard			Occupational Risk[c]	
			Aquatic	Dermal[a]	Inhalation[ab]	Dermal	Inhalation
Ethylene glycol ethers							
Water	Alcohols, C11-15-secondary, ethoxylated 68131-40-8	SAT	M	M/M	M/M	clear	n.e.
	Butyl carbitol 112-34-5	Tox	L	L/L	M/L	clear	clear
	Ethoxylated tetramethyldecyndiol 9014-85-1	SAT	L	L-M/NA	L-M/NA	potential	n.e.
	Ethyl carbitol 111-90-0	Tox	L	M-H/L	M-H/L	clear	clear
	Polyethylene glycol 25322-68-3	Tox	L	L/NA	L/NA	potential	n.e.

[a] The first letter(s) represents systemic concern, the second represents developmental concerns. L= Low; M = Medium; H = High; NA = No data or information are available; n.e. = No Exposure
[b] Inhalation hazard information was not included for compounds that are not expected to be volatile (i.e., that have a vapor pressure <0.001 mmHg).
[c] Dermal occupational risk concern ratings are applicable for press and prep room workers; inhalation risk concern ratings are applicable for press room workers. The risk concern levels shown here represent the highest observed risk rating.

Other Suggestions for Reducing Impacts of Flexographic Inks

DfE partners, particularly the Steering Committee, include the major trade associations in the flexographic ink industry. These partners are an excellent source of information on both industry trends and concerns. Their willingness to maintain continued partnership with DfE over the years demonstrates their commitment to providing the industry with sound environmental information. Trade associations are considered essential DfE partners during a project as well as for industry-wide communication and implementation of project results. Associations are key to sharing information, including incentives to making change and recognition of businesses that have overcome obstacles.

In addition to your trade association, other useful resources include the EPA's Office of Pollution Prevention and Toxic's (OPPT) website. Please visit the site <http://www.epa.gov/opptintr/database.htm#cheminfo> to find tools, models, and chemical information for better understanding chemicals.

Also, important information on chemical categories can be found at the EPA's New Chemicals website <http://www.epa.gov/opptintr/newchems/chemcat.htm>. The chemical categories broadly describe potential concerns for substances that may fall into a specific chemical category. The category also describes bounds for determining whether a specific chemical substance, that would generally fall into a category, actually might be considered of concern. A category statement describes the molecular structure a chemical might have to be included in the category as well as boundary conditions such as molecular weight, equivalent weight, the log of the octanol/water partition coefficient (log P), or water solubility, that would determine inclusion in (or exclusion from) a category, and standard hazard and fate tests to address concerns for the category. Currently, there are a total of 45 categories.

A few excellent secondary sources of chemical information include the following:

- **The Hazardous Substances Data Bank, in TOXNET:**
  <http://toxnet.nlm.nih.gov>
- **Agency for Toxic Substances and Disease Registry (ASTDR):**
  <http://www.atsdr.cdc.gov/>
- **The National Library of Medicine Toxicology and Environmental Health Specialized Information Services:**
  <http://sis.nlm.nih.gov/tehip1.htm>
- **TOXLINE:** The National Library of Medicine's extensive collection of online bibliographic information covering the biochemical, pharmacological, physiological, and toxicological effects of drugs and other chemicals.
  <http://toxnet.nlm.nih.gov/cgi-bin/sis/htmlgen?TOXLINE>
- **Integrated Risk Information System (IRIS):**
  <http://www.epa.gov/iris>

The DfE website (www.epa.gov/dfe) may also serve as a source of information on other chemical substances. The DfE Program has reviewed many other substances in similar cleaner technology evaluations, including previous partnerships focused on the activities of screen and lithographic printers.

There is another message here in understanding chemicals in the workplace: To be a proactive decision-maker, it is critical to have the best information available. Building as well as choosing a product formulation with a more positive environmental profile may require extra care and scrutiny, especially when selecting raw materials. A material data safety sheet (MSDS) and the product label provide an excellent starting place for understanding the potential impacts of a chemical; however, the MSDS or label may not provide all the information needed to make a better choice. Often, chemicals are generically described by chemical class or, by trade name. Structural and other differences in chemicals of the same general class and makeup may not be apparent from product literature or labels, especially for imported substances. Descriptions in distributor or supplier literature and catalogs may define a chemical type but not detail a chemical's actual structure (e.g., whether a carbon chain is branched or linear – a key distinction from an environmental standpoint since linear chains biodegrade more rapidly than branched). Also, sales materials may only list trade names, often an imprecise descriptor, since a name might remain the same while the actual product composition may change. The databases and resources described above identify chemical substances by specific chemical name; it is important to get correct chemical identify information that includes Chemical Abstract Service (CAS) names and CAS numbers when doing research on chemical formulations.

DfE encourages you to visit our website for more information on the DfE formulator initiative, at http://www.epa.gov/dfe/projects/formulat/index.htm. The DfE Program offers partnership and recognition to companies that act as environmental stewards by improving the environmental profile of their formulated products and processes.

Table ES.13 presents some suggestions for how flexographic professionals can quickly and easily take actions that may reduce the health and environmental impacts of using flexographic inks. The CTSA also includes more general ways to implement pollution prevention related to the flexographic industry.

Table ES.13 Ways to Reduce Environmental and Health Impacts of Flexographic Inks

Suggestion	Printers	Formulators	Other (Technology Assistance Providers, Colleges, etc.)
Read flexographic CTSA materials to become familiar with environmental and health impacts of chemicals in inks.	X	X	X
Select the cleanest inks that make business sense. Minimize use of hazardous inks.	X		
Minimize the need for and use of press-side solvents and other additives.	X	X	
Maximize good ventilation, particularly in the prep and press rooms.	X		
Ensure that all workers who handle inks wear butyl or nitrile gloves, to minimize exposure to chemicals.	X		
Ensure that all pollution control devices are maintained properly and work correctly at all times.	X		
Identify ways to improve operations and environmental performance by looking at all steps in the printing process throughout the facility.	X		X
Develop comprehensive safe working policies and practices for inks, and ensure that workers follow them.	X		X
Minimize the amount and number of hazardous ingredients in inks.		X	
Work to make environmental and health information about inks more accessible and understandable.		X	
Support research on untested and inadequately tested flexographic ink chemicals, especially those with clear or potential risk concerns and those that are produced in high quantities (high production volume chemicals).	X	X	X

REFERENCES

1. U.S. Census, 1999 Survey of Manufactures.

2. U.S. Census. 1997. Commercial Flexographic Printing.

3. *Flexo*, December 1998. "1999 Industry Forecasts," p. 32.

4. U.S. Census. 1997. Commercial Flexographic Printing.

5. National Association of Printing Ink Manufacturers. 2001 *State of the Industry Report,* p 4 (Printing Ink 2000 Market).

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